GUIDE FOR MAKING
VOLTAGE DROP CALCULATIONS

REA BULLETIN 45-1

RURAL ELECTRIFICATION ADMINISTRATION·U.S.DEPARTMENT OF AGRICULTURE
JULY 1978

FOREWORD

This bulletin is a guide for making voltage drop calculations on distribution primary lines of standard REA designs.

Voltage drop factors have been calculated for use with distances in kilometers rather than in miles.

Previously, voltage drop factors were available only for 0.90 power factor lagging. Voltage drop factors have now been included for 0.85 and 0.95 power factor as well. Also included are voltage drop factors for URD cable.

Although 34.5 kV is not recognized as a distribution voltage by REA, voltage drop factors have been included for 34.5 kV overhead construction.

A discussion of the use of a computer for voltage drop calculations has been added.

This bulletin replaces REA Bulletin 45-1, dated March 1957.

Richard F. Richter

Assistant Administrator - Electric

Index:
  VOLTAGE:
    Drop Calculations

UNITED STATES DEPARTMENT OF AGRICULTURE
Rural Electrification Administration

July 12, 1978
Supersedes 3/57

REA BULLETIN 45-1

SUBJECT: Guide for Making Voltage Drop Calculations

INTRODUCTION

Rural distribution systems are to be designed and operated so that acceptable standards of service will be maintained. One of these service standards is the proper voltage level (see Bulletin 169-4). This bulletin is a guide for making voltage drop calculations on distribution primary lines of standard REA designs. Examples of voltage drop calculations have been included to facilitate more complete understanding of the procedures and methods given in this guide. Also included is a blank voltage drop form which may be reproduced locally.

PROCEDURE

Information Required

As a basis for the preparation of voltage drop calculations, the following information relative to the system or portion of the system should be on hand:

1. A Circuit Diagram prepared in accordance with REA Bulletin 60-1. All areas and loads which are to be served by the system design for which the voltage drop calculations are being made should be shown on the Circuit Diagram. Although a Circuit Diagram may serve the dual purpose of voltage drop calculations and sectionalizing studies, a separate Circuit Diagram for the voltage drop calculations is recommended.

2. The number of consumers for each section of each circuit of a balanced design.

3. The number of consumers for each phase of each section of each circuit of an unbalanced design.

Basis for Calculation

Individual line voltage drop calculations should be based upon relative load levels which are consistent with the overall system design level. However, this does not preclude using the methods given in this bulletin for estimating future voltage drops using a load growth rate for a given time which is greater or less than the overall system.

Voltage Drop calculations are referred to a 120 volt base.

$$\text{Voltage Drop (120 volt base)} = \frac{\text{Actual Voltage Drop X 120}}{\text{System Nominal Voltage}}$$

For Example:

Nominal System Voltage = 12.47 grounded wye/7.2 kV

Actual Voltage Drop = 360 volts

$$\text{Voltage Drop (120 volt base)} = \frac{360}{7200} \text{ X } 120 = 6 \text{ volts}$$

The lines on the Circuit Diagram are divided into sections with the ends of the sections at the following points:

1. Substations

2. Major taps and at the ends of such taps--(A major tap is defined as a tap having a load which is estimated to be equal to at least 20 percent of line load at that point.)

3. Change in the number of phases

4. Conductor size changes

5. Underground to overhead changes

6. Large concentrated loads--(A large concentrated load is defined as a load which is estimated to equal at least 20 percent of line load at that point.)

Balanced Circuit Calculations

The following instructions are given for completing the Voltage Drop Sheet (sample enclosed) when calculating voltage drop on balanced circuits. A balanced circuit is defined as a multi-phase line loaded so that the estimated load of any phase is neither less than 80 percent nor greater than 120 percent of the average per phase load.

Columns 1 & 2 - Starting at the ends of the circuit farthest from the substation, designate the section being considered by the same designation used to identify the points previously marked on the Circuit Diagram to indicate the ends of the sections. For example, "3AC13-3A16" on Exhibits 3 and 5 designates the "V" phase line composed of phases A & C between points 13 and 16 of circuit number 3.

Column 3 - This column shows the number of consumers (corresponding to the system design) within the section including minor taps within the section.

BIND

:File With REA:
:Bulletin 45-1:

UNITED STATES DEPARTMENT OF AGRICULTURE
Rural Electrification Administration

December 12, 1978

SUBJECT: Replacement Pages and Pen and Ink Changes for REA Bulletin 45-1, Guide for Making Voltage Drop Calculations

TO: Electric Borrowers and Consulting Engineers

Attached are replacement copies of pages 15, 16 and 17. Please remove old pages 15, 16 and 17 from your copy of REA Bulletin 45-1 and insert the replacement pages.

Also, please make the following pen and ink changes to this bulletin.

Exhibit 3 - change point designation "3836" to "3B36"

Page 13 - last equation on the page should read:

$$VD = \frac{(kW)\ \ (r \cos\theta + x \sin\theta)\ (120)}{(kV)^2\ (\cos\theta)\ \ (P)\ \ (1000)}$$

Richard F. Richter

RICHARD F. RICHTER
Assistant Administrator - Electric

Attachments

TABLE III
VOLTAGE DROP FACTORS
FOR
REA DISTRIBUTION LINES
FOR 95 PERCENT POWER FACTOR
VOLTAGE DROP FACTOR

LINE-TO-NEUTRAL NOMINAL VOLTAGE	SINGLE PHASE 7.2 kV	SINGLE PHASE 7.62 kV	SINGLE PHASE 14.4 kV	SINGLE PHASE 19.9 kV	"V" PHASE 7.2 kV	"V" PHASE 7.62 kV	"V" PHASE 14.4 kV	"V" PHASE 19.9 kV	THREE PHASE 7.2 kV	THREE PHASE 7.62 kV	THREE PHASE 14.4 kV	THREE PHASE 19.9 kV
CONDUCTOR SIZE (ALUMINUM)					(OVERHEAD)							
336.6 kcmil									.233	.208	.0583	.0305
266.8 kcmil									.271	.242	.0677	.0354
4/0	1.50	1.34	.374	.196	.746	.671	.187	.0981	.324	.289	.0807	.0423
3/0	1.70	1.51	.423	.222	.845	.758	.212	.111	.382	.341	.0950	.0498
2/0	2.00	1.78	.500	.262	1.00	.895	.250	.131	.454	.405	.113	.0593
1/0	2.30	2.05	.574	.301	1.15	1.03	.287	.150	.544	.485	.136	.0708
2	3.05	2.73	.764	.400	1.53	1.36	.382	.200	.802	.715	.199	.104
4	4.24	3.79	1.06	.556	2.12	1.90	.531	.278	1.20	1.08	.300	.157
6	6.08	5.42	1.52	.795	3.04	2.72	.758	.398	1.81	1.62	.454	.238
					(UNDERGROUND)							
350 kcmil	.979	.874	.247		.366	.327	.0898		.234	.209	.0574	
250 kcmil	1.37	1.22	.345		.468	.418	.115		.299	.267	.0735	
4/0	1.61	1.44	.405		.533	.476	.131		.340	.303	.0837	
3/0	1.98	1.77	.497		.643	.574	.159		.408	.364	.101	
2/0	2.40	2.14	.600		.793	.708	.197		.502	.448	.125	
1/0	2.87	2.56	.716		.961	.858	.239		.606	.541	.150	
1	3.40	3.04	.849		1.20	1.07	.298		.753	.672	.187	
2	3.99	3.56	.995		1.48	1.32	.368		.924	.856	.230	

Column 4 - This column shows the number of consumers beyond the section being considered that are supplied power which must flow all the way through this section. This number is obtained by adding the numbers in Column 3 which pertain to sections beyond the section being considered plus the number of consumers in any taps that are beyond the section being considered but not included in column 3.

Column 5 - This column shows the equivalent number of consumers that are supplied through the section being considered. This number is obtained by adding one-half the consumers shown in column 3 to the number of consumers shown in column 4. The number in column 3 is multiplied by one-half in order to reflect the fact that the load is spread over the entire section rather than being concentrated at the end of the section.

Column 6 - This column shows the average kilowatt hour consumption per consumer per month used for the circuit.

Column 7 - The peak kilowatt demand for the number of consumers shown in column 5 is entered in this column. Peak kilowatt demand is read directly from the Demand Tables (REA Bulletin 45-2) for the number of consumers shown in column 5 and the kilowatt-hour consumption per consumer shown in column 6. Bulletin 45-2 also shows how to adapt tables to different system load factors.

Column 8 - Enter the contributing peak load of the concentrated loads within the section being considered.

Column 9 - Enter the contributing peak load at the end of and beyond the section being considered.

Column 10 - Enter the total equivalent contributing peak load of the concentrated loads, column 9 plus one-half of column 8.

Column 11 - Enter the total equivalent load for the section, column 10 plus column 7.

Column 12 - Enter power factor for this section. Remember to consider the load that flows through this section as well as loads within this section. The power factor should be derived by a qualified engineering study. If no data is available, use 90 percent power factor.

Column 13 - Enter the conductor size (aluminum) used in this section. If copper conductor is used, the equivalent size aluminum conductor is generally two sizes larger. (See Appendix A.) Also, note if this section is underground.

Column 14 - Indicate the number of phases in the section being considered.

Column 15 - Indicate the line-to-ground voltage (in kilovolts) of the line.

Column 16 - These values are from Appendix A for the power factor, conductor size, number of phases, and voltage given in columns 12, 13, 14 and 15.

Column 17 - Show the total length, in kilometers, of the section being considered.

Column 18 - Show the kilowatt-kilometers which are the product of the figures in columns 11 and 17.

Column 19 - Enter the voltage drop in the section. These values are obtained by applying the equation:

$$\text{Voltage Drop (120 volt base)} = \frac{\text{(Total kW) (Kilometers) (Voltage Drop Factor)}}{1000}$$

$$= \frac{\text{(Column 18) (Column 16)}}{1000}$$

Column 20 - This column shows the voltage drop at the load end of each section. The values are found by starting with the section nearest to the source and summing up the voltage drops in all the sections between the source and the section being considered, including the voltage drop in this section. The voltage drop thus caluclated applies at the load end of each section being considered.

Column 21 - This column shows the point at which the calculated voltage drop applies. The designation is that of the load end of the respective sections, same as column 2.

Unbalanced Circuit Calculations

On unbalanced circuits the voltage drop is calculated for each phase separately for the loads on that particular phase only. An unbalanced circuit is defined as a multiphase line loaded so that the estimated load of any phase is less than 80 percent or greater than 120 percent of the average per phase load. On unbalanced circuits the voltage drop factor for "V" phase lines is twice the "V" phase voltage drop factor for balanced circuits (for overhead circuits twice the "V" phase voltage drop factor is equal to the single-phase voltage drop factor), and for three-phase lines, it is equal to three times the voltage drop factor for three-phase balanced circuits.

REPORT OF CALUCLATIONS AND RESULTS

A complete report of the calculations and results should consist of the following:

1. Basic Data

   a. Tabular summary of all consumers by classifications.

   b. Tabular summary of the number of concentrated loads (such as irrigation, oil well pumping, etc.) with their kW demands.

   c. Design kWh/mo./con. for all consumers, except for those included in (b) above.

2. Completed Voltage Drop Circuit Diagrams.

3. Voltage Drop Sheets.

4. Explanatory Comments:

   a. Basis for design kWh/mo./con. for the system.

   b. Basis for design kWh/mo./con. for the substations and feeders.

   c. Basis for calculating contribution demand of such loads as irrigation, oil well pumping or house heating.

   d. Basis for power factor

The basic data should be developed and presented in such a manner as to show the number and size of all loads considered and as to facilitate future voltage analysis required due to unforeseen changes in loading.

Completed Voltage Drop Circuit Diagrams should be prepared in accordance with REA Bulletin 60-1.

Exhibits 4 and 5 illustrate complete Voltage Drop Sheets.

Explanatory comments should discuss any factors affecting the calculations, but which are not readily discernible from the Basic Data, Circuit Diagrams or Voltage Drop Sheets. Two examples would be: (1) calculations based upon summer loading plus irrigation and air conditioning, (2) calculations based upon winter loading excluding irrigation and air conditioning. Before any changes are made to the system, such as reconductoring, the voltage at the points in question should be measured using a meter in order to verify the calculations.

EXAMPLES

Examples of voltage drop calculations have been included to facilitate more complete understanding of the procedures and methods given in this guide. Exhibits 1, 2 & 3 are excerpts from a complete circuit diagram which have been modified for purposes of illustration. No diversity was included in the samples. Diversity may be taken into account in accordance with REA Bulletin 45-2, "Demand Tables," and should be noted as part of the explanatory comments.

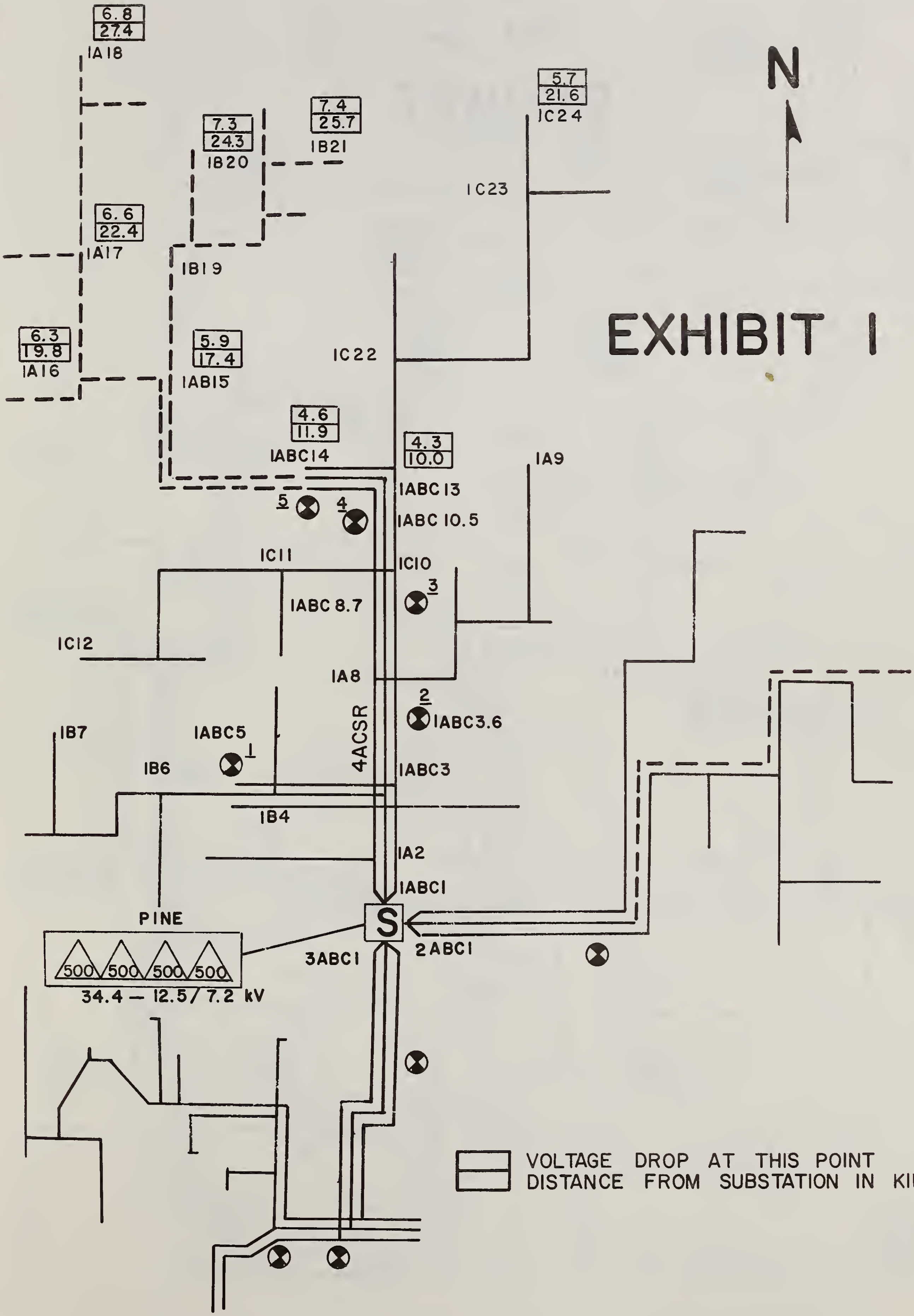
The circuit diagram and voltage drop calculations for circuit 1ABC are shown in Exhibits 1 and 4. This circuit has a balanced load as defined in the instructions for calculations of balanced circuits. All concentrated loads and taps between points 1ABC1 and 1ABC13 are included in one section for voltage drop calculation purposes. This is in accordance with the "Basis for Calculations," given in the procedure. Applying these rules for determining sections for voltage drop calculations results in fewer calculations, but does little to decrease the accuracy of the calculations.

The circuit diagram and voltage drop calculations for circuit 2ABC are shown in Exhibits 2 and 4. This circuit has an unbalanced load as defined in the instructions for calculations of unbalanced circuits. Each phase and its associated loads are calculated independently. Unbalanced circuit calculations are less accurate than balanced circuit calculations. Where circuit parameters and loads make unbalanced design an economic necessity, they are considered necessary but not desirable. For such circuits, voltage drop calculations as illustrated are sufficiently accurate for design purposes.

The circuit diagram and voltage drop calculations for circuit 3ABC are shown in Exhibits 3 and 5. This example is included to illustrate voltage drop calculation procedure when a voltage regulator is to be used. The procedure does not change. Voltage drop calculations are not influenced by the fact that a voltage regulator is to be included. Having completed the voltage drop calculations, the voltage regulator is shown on the circuit diagram at the "half-voltage-drop" point. Also, note that the summary of loads for circuit 3ABC shows a 35 kW off-peak load (No. 10 on Exhibit 3) which although connected to the circuit is not included in the calculations.

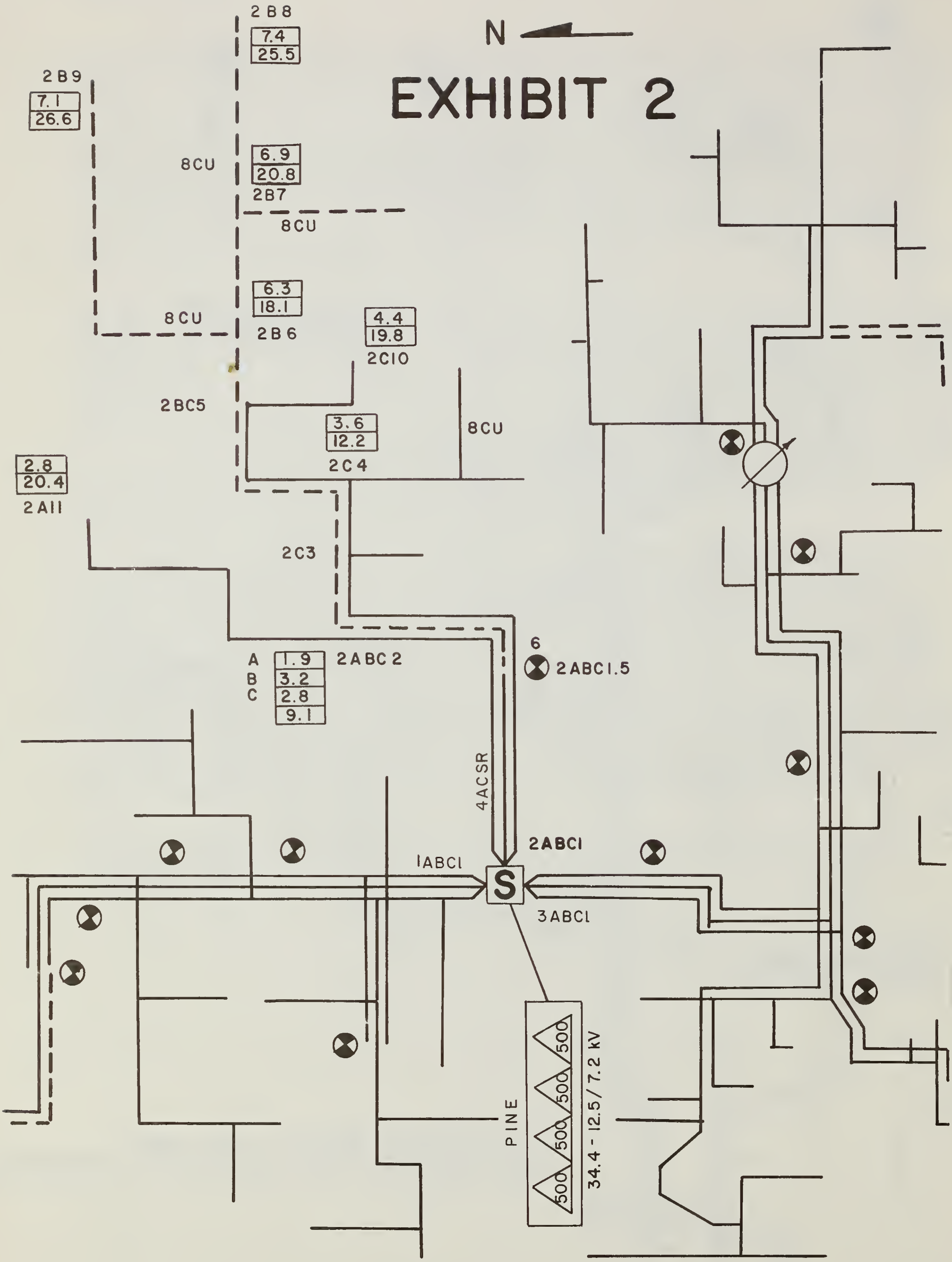
Please note that when a copper conductor is used, the entry on the voltage drop form is that of the equivalent size aluminum conductor (normally two AWG sizes larger). (See Appendix A)

EXHIBIT I



VOLTAGE DROP AT THIS POINT
DISTANCE FROM SUBSTATION IN KILOMETERS

EXHIBIT 2


N
2B8
7.4
25.5
2B9
7.1
26.6
8CU
6.9
20.8
2B7
8CU
6.3
18.1
8CU
2B6
4.4
19.8
2C10
2BC5
3.6
12.2
2C4
8CU
2.8
20.4
2A11
2C3
6
2ABC1.5
A 1.9
B 3.2
C 2.8
9.1
2ABC2
4ACSR
2ABC1
1ABC1
S
3ABC1
PINE
500
500
500
500
34.4 - 12.5/7.2 kV

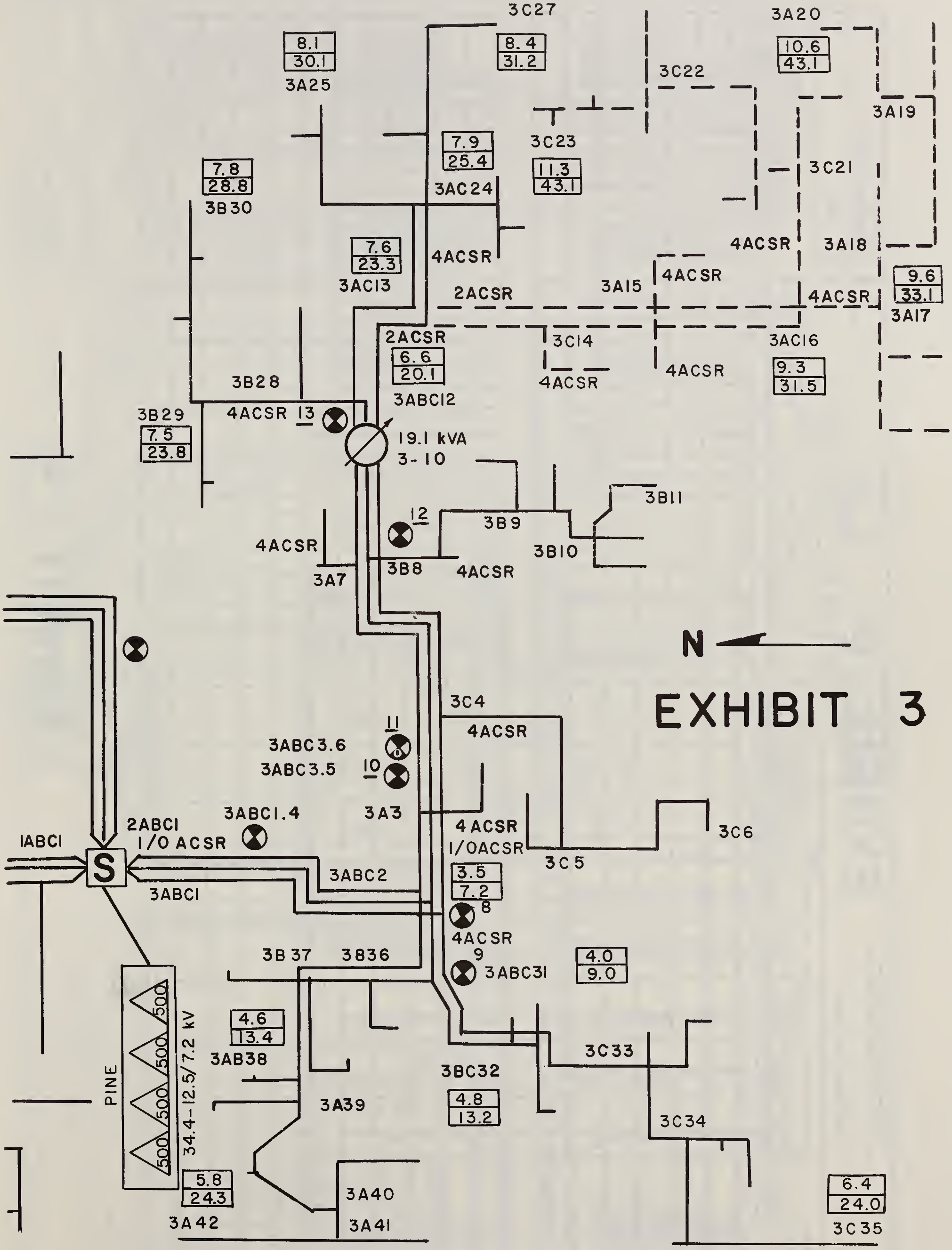

3C27
8.1
30.1
3A25
8.4
31.2
3C22
3A20
10.6
43.1
3A19
7.9
25.4
3C23
11.3
43.1
3C21
7.8
28.8
3B30
3AC24
7.6
23.3
3AC13
4ACSR
4ACSR
3A18
3A15
4ACSR
2ACSR
4ACSR
9.6
33.1
3A17
2ACSR
6.6
20.1
3C14
3AC16
4ACSR
4ACSR
9.3
31.5
3B28
3ABC12
3B29
7.5
23.8
4ACSR
13
19.1 kVA
3-10
3B11
12
3B9
4ACSR
3B10
3A7
3B8
4ACSR
N
3C4
4ACSR
11
3ABC3.6
3ABC3.5
10
3ABC1.4
3A3
2ABC1
1/0 ACSR
IABC1
S
4 ACSR
1/0ACSR
3C5
3C6
3ABC1
3ABC2
3.5
7.2
8
4ACSR
9
3ABC31
4.0
9.0
3B 37
3836
4.6
13.4
3AB38
PINE
500
500
500
500
34.4-12.5/7.2 kV
3A39
3BC32
4.8
13.2
3C33
3C34
5.8
24.3
3A42
3A40
3A41
6.4
24.0
3C35

EXHIBIT 3

U. S. DEPARTMENT OF AGRICULTURE
RURAL ELECTRIFICATION ADMINISTRATION

VOLTAGE DROP SHEET

SYSTEM DESIGNATION	SUBSTATION	SYSTEM DESIGN
Somestate 2 Deal	Pine	380 kWh/mo./cons.
SYSTEM ENGINEER	**CIRCUITS**	**DATE**
Valley Engineering Co.	1 ABC and 2 ABC	Dec. 1977

SECTION		LOAD										LINE						VOLTAGE DROP		
		CONSUMERS					CONCENTRATED													
SOURCE END	LOAD END	WITHIN THIS SECTION	BEYOND THIS SECTION	EQUIV. THIS SECTION	kWh PER MONTH	PEAK kW	WITHIN THIS SECTION	BEYOND THIS SECTION	EQUIV. THIS SECTION	TOTAL kW	POWER FACTOR	CONDUCTOR SIZE ALUMINUM	ϕ	kV	VOLTAGE DROP FACTOR	LENGTH OF SECTION IN km	kW·km	THIS SECTION	TOTAL	AT POINT
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1A17	1A18	10	0	5	300	9				9	90%	4	1	7.2	4.57	5.0	45.0	.2	6.8	1A18
1A16	1A17	6	13	16	300	22				22		4	1		4.57	2.6	57.2	.3	6.6	1A17
1AB15	1A16	4	24	26	300	33				33		4	1		4.57	2.4	79.2	.4	6.3	1A16
1B20	1B21	10	0	5	300	9				9		4	1		4.57	1.4	12.6	.1	7.4	1B21
1AB15	1B20	43	16	37	300	45				45		4	1		4.57	6.9	310.5	1.4	7.3	1B20
1ABC14	1AB15	10	87	92	300	101				101		4	V		2.29	5.5	555.5	1.3	5.9	1AB15
1ABC13	1ABC14	5	97	99	300	107	12	25	31	138		4	3		1.26	1.9	262.2	.3	4.6	1ABC14
1ABC13	1C24	40	0	20	300	27				27		4	1		4.57	11.6	313.2	1.4	5.7	1C24
1ABC1	1ABC13	120	142	202	300	203	209	37	141	344		4	3		1.26	10.0	3440.0	4.3	4.3	1ABC13
Sub.			262		300	257		246		503										
Summary:	262 farm, non-farm, small commercial and school and church consumers at 300 kWh/mo 3 irrigation @ 25 kW, 1 large commercial @ 35 kW, 1 industrial @ 40 kW, and 8 small irrigation loads @ approx. 12 kW																			
2B7	2B8	12	0	6	500	16				16	90%	6	1	7.2	6.40	4.7	75.2	.5	7.4	2B8
2B6	2B7	6	21	24	500	49				49		4	1		4.57	2.7	132.3	.6	6.9	2B7
2B6	2B9	13	0	6	500	16				16		6	1		6.40	8.5	136.0	.8	7.1	2B9
2B2	2B6	0	40	40	500	76				76		4	V		4.57	9.0	684.0	3.1	6.3	2B6
2C4	2C10	19	0	9	500	22				22		4	V		4.57	7.6	167.2	.8	4.4	2C10
2C2	2C4	8	24	28	500	56				56		4	V		4.57	3.1	173.6	.8	3.6	2C4
2A2	2A11	14	0	7	500	18				18		4	1		4.57	11.3	203.4	.9	2.8	2A11
2A1	2A2	7	14	17	500	37	34	0	17	54		4	3		3.78	9.1	491.4	1.9	1.9	2A2
2B1	2B2	0	40	40	500	76	34	0	17	93		4	3		3.78	9.1	846.3	3.2	3.2	2B2
2C1	2C2	0	32	32	500	63	34	0	17	80		4	3		3.78	9.1	728.0	2.8	2.8	2C2
Sub.			93		500	160		102		262										
Summary:	93 farm, non-farm, small commercial and school and church consumers at 500 kWh/mo 1 industrial @ 45 kW and 7 small concentrated loads @ approx. 8 kW																			

EXHIBIT 4

U. S. DEPARTMENT OF AGRICULTURE
RURAL ELECTRIFICATION ADMINISTRATION

VOLTAGE DROP SHEET

SYSTEM DESIGNATION	SUBSTATION	SYSTEM DESIGN
Somestate 2 Deal	Pine	380/kWh/mo./cons.
SYSTEM ENGINEER	CIRCUITS	DATE
Valley Engineering Company	. 3 ABC	December 1977

SECTION		LOAD										LINE						VOLTAGE DROP		
		CONSUMERS					CONCENTRATED													
SOURCE END	LOAD END	WITHIN THIS SECTION	BEYOND THIS SECTION	EQUIV. THIS SECTION	kWh PER MONTH	PEAK kW	WITHIN THIS SECTION	BEYOND THIS SECTION	EQUIV. THIS SECTION	TOTAL kW	POWER FACTOR	CONDUCTOR SIZE ALUMINUM	ϕ	kV	VOLTAGE DROP FACTOR	LENGTH OF SECTION IN km	kW·km	THIS SECTION	TOTAL	AT POINT
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
3A17	3A20	25	0	12	400	22				22	90%	4	1	7.2	4.57	10.0	220.0	1.0	10.6	3A20
3AC16	3A17	6	25	28	400	46				46		4	1		4.57	1.6	73.6	.3	9.6	3A17
3AC16	3C23	45	0	22	400	38				38		4	1		4.57	11.6	440.8	2.0	11.3	3C23
3AC13	3AC16	17	76	84	400	119				119		2	V		1.69	8.2	975.8	1.7	9.3	3AC16
3AC24	3A25	11	0	5	400	11				11		4	1		4.57	4.7	51.7	.2	8.1	3A25
3AC24	3C27	18	0	9	400	18				18		4	1		4.57	5.8	104.4	.5	8.4	3C27
3AC13	3AC24	5	36	38	400	60				60		4	V		2.29	2.1	126.0	.3	7.9	3AC24
3AC12	3AC13	6	134	137	400	183				183		2	V		1.69	3.2	585.6	1.0	7.6	3AC13
3B29	3B30	10	0	5	400	11				11		4	1		4.57	5.0	55.0	.3	7.8	3B30
3ABC12	3B29	8	29	33	400	53				53		4	1		4.57	3.7	196.1	.9	7.5	3B29
3ABC2	3ABC12	87	177	220	400	283	151	40	115	398		1/0	3		.60	12.9	5134.2	3.1	6.6	3ABC12
3AB38	3A42	27	0	13	400	24				24		4	1		4.57	10.9	261.6	1.2	5.8	3A42
3AB31	3AB38	24	27	39	400	61				61		4	V		2.29	4.4	268.4	.6	4.6	3AB38
3BC32	3C35	36	0	18	400	32				32		4	1		4.57	10.8	345.6	1.6	6.4	3C35
3ABC31	3BC32	18	47	56	400	84				84		4	V		2.29	4.2	352.8	.8	4.8	3BC32
3ABC2	3ABC31	3	116	117	400	160	13	45	51	211		4	3		1.26	1.8	379.8	.5	4.0	3ABC31
3ABC1	3ABC2	12	383	389	400	479	103	284	337	816		1/0	3		.60	7.2	5875.2	-3.5	3.5	3ABC2
Sub			395		400	485		387		872										

Summary: 395 farm, non-farm, small commercial and school and church consumers @ 400 kWh/mo.
3 industrials @ 60, 45 and 40 kW, 1 large commercial @ 35 kW, 2 irrigation @ 30 and 25 kW.
1-35 kW off-peak load @ 0 kW and 10 small concentrated loads @ approx. 15 kV.

EXHIBIT 5

APPENDIX A

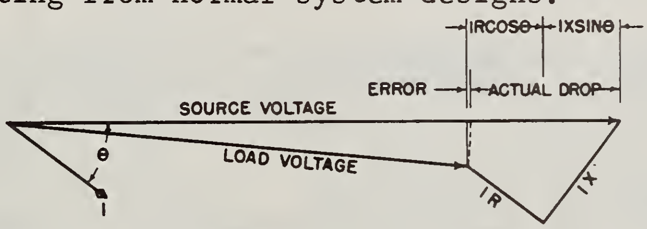
VOLTAGE DROP FACTORS

Voltage drop for known source-end and lagging power factor conditions may be calculated from the following equation:

$$\text{Voltage Drop} = I(r \cos \theta + x \sin \theta)$$

Where: I = Line current in amperes
θ = Phase angle between voltage and current
r = Resistance of line in ohms
x = Reactance of line in ohms

It can be seen from the vector diagram that this approximate equation is sufficiently accurate for the magnitude and phase angle of the vectors resulting from normal system designs.



Line current may be expressed in terms of kilowatts and voltage as follows:

$$I = \frac{kW}{(kV)\ (\cos \theta)\ (P)}$$

Where: kW = Circuit load in kilowatts
kV = System nominal phase-to-ground voltage in kilovolts
P = Number of phases

Voltage drop referred to a 120 volt base (VD) is expressed as follows:

$$VD = \frac{\text{Actual Voltage Drop (120)}}{\text{System Nominal Voltage}}$$

Using the above equations for line current and voltage drop referred to a 120 volt base (VD), the equation for voltage drop becomes:

$$VD = \frac{(kW\ \ (r \cos \theta + x \sin \theta)\ \ (120)}{(kV)^2\ (\cos \theta)\ \ (P)\ \ (1000)}$$

The equation for (VD) expressed in per kilometer units is written as follows:

$$VD = \frac{(kW)\ (R \cos \theta + X \sin \theta)\ (S)\ (120)}{(kV)^2\ (\cos \theta)\ (P)\ (1000)}$$

Where: R = Resistance in ohms per phase per kilometer of line
X = Reactance in ohms per phase per kilometer of line
S = Line distance in kilometers

Letting the following factor be designated the voltage drop factor (VDF):

$$\frac{(R \cos \theta + X \sin \theta)\ (120)}{(kV)^2\ (\cos \theta)\ (P)}$$

the equation for (VD) becomes:

$$VD = \frac{(kW)\ (S)\ (VDF)}{1000}$$

Tables I, II, and III give the Voltage Drop Factors (VDF) for calculating voltage drops of overhead and underground (URD) distribution lines constructed in accordance with REA standard specifications. Voltages given in the tables are line-to-neutral voltages.

The following table gives the equivalent aluminum size conductor for given copper sizes.

Aluminum	Copper
336.6 kcmil	4/0
266.8 kcmil	3/0
4/0	2/0
3/0	1/0
2/0	1
1/0	2
2	4
4	6
6	8

TABLE I
VOLTAGE DROP FACTORS
FOR
REA DISTRIBUTION LINES
FOR 85 PERCENT POWER FACTOR
VOLTAGE DROP FACTOR

LINE-TO-NEUTRAL	SINGLE PHASE				"V" PHASE				THREE PHASE			
NOMINAL VOLTAGE	7.2 kV	7.62 kV	14.4 kV	19.9 kV	7.2 kV	7.62 kV	14.4 kV	19.9 kV	7.2 kV	7.62 kV	14.4 kV	19.9 kV
CONDUCTOR SIZE (ALUMINUM)					(OVERHEAD)							
336.6 kcmil									.321	.287	.0802	.0421
266.8 kcmil									.362	.323	.0907	.0473
4/0	2.01	1.80	.502	.263	1.01	.895	.251	.132	.423	.378	.106	.0553
3/0	2.22	1.99	.556	.291	1.11	.994	.278	.145	.483	.431	.121	.0633
2/0	2.57	2.30	.646	.337	1.29	1.15	.322	.168	.557	.497	.139	.0727
1/0	2.90	2.59	.727	.380	1.45	1.30	.363	.190	.646	.579	.162	.0851
2	3.67	3.27	.920	.480	1.83	1.64	.459	.240	.907	.808	.227	.119
4	4.85	4.33	1.21	.634	2.43	2.17	.607	.318	1.31	1.17	.328	.172
6	6.71	6.00	1.68	.882	3.36	3.00	.839	.440	1.94	1.73	.484	.254
					(UNDERGROUND)							
350 kcmil	1.05	.936	.267		.414	.370	.102		.265	.237	.0656	
250 kcmil	1.47	1.32	.373		.525	.469	.130		.336	.300	.0830	
4/0	1.74	1.55	.440		.593	.530	.147		.379	.339	.0939	
3/0	2.15	1.92	.542		.707	.632	.175		.451	.403	.112	
2/0	2.61	2.33	.656		.862	.769	.214		.548	.489	.136	
1/0	3.14	2.81	.789		1.03	.923	.257		.654	.584	.163	
1	3.74	3.34	.936		1.27	1.14	.318		.803	.717	.200	
2	4.69	4.19	1.17		1.71	1.53	.427		1.07	.959	.268	

TABLE II
VOLTAGE DROP FACTORS
FOR
REA DISTRIBUTION LINES
FOR 90 PERCENT POWER FACTOR
VOLTAGE DROP FACTOR

	SINGLE PHASE				"V" PHASE				THREE PHASE			
LINE-TO-NEUTRAL NOMINAL VOLTAGE	7.2 kV	7.62 kV	14.4 kV	19.9 kV	7.2 kV	7.62 kV	14.4 kV	19.9 kV	7.2 kV	7.62 kV	14.4 kV	19.9 kV
CONDUCTOR SIZE (ALUMINUM)					(OVERHEAD)							
336.6 kcmil									.280	.250	.0702	.0367
266.8 kcmil									.319	.285	.0802	.0418
4/0	1.77	1.58	.442	.232	.882	.789	.221	.117	.363	.324	.0907	.0475
3/0	1.98	1.76	.495	.259	.988	.882	.247	.129	.436	.389	.109	.0570
2/0	2.31	2.06	.577	.302	1.16	1.03	.288	.151	.509	.454	.127	.0664
1/0	2.62	2.34	.652	.343	1.31	1.17	.327	.172	.600	.536	.150	.0782
2	3.38	3.02	.845	.443	1.69	1.51	.423	.221	.858	.744	.214	.112
4	4.57	4.08	1.14	.598	2.29	2.04	.571	.299	1.26	1.12	.315	.165
6	6.40	5.74	1.60	.839	3.21	2.86	.802	.421	1.88	1.68	.470	.246
					(UNDERGROUND)							
350 kcmil	1.02	.907	.258		.392	.350	.0965		.251	.224	.0618	
250 kcmil	1.42	1.27	.360		.499	.445	.123		.318	.284	.0786	
4/0	1.68	1.50	.424		.565	.505	.140		.361	.322	.0891	
3/0	2.07	1.85	.521		.677	.605	.168		.431	.385	.107	
2/0	2.51	2.24	.630		.830	.741	.206		.527	.470	.131	
1/0	3.01	2.69	.755		1.00	.892	.249		.631	.564	.157	
1	3.58	3.20	.896		1.24	1.11	.309		.780	.696	.194	
2	4.49	4.01	1.12		1.67	1.49	.416		1.04	.933	.260	

TABLE I
VOLTAGE DROP FACTORS
FOR
REA DISTRIBUTION LINES
FOR 85 PERCENT POWER FACTOR
VOLTAGE DROP FACTOR

LINE-TO-NEUTRAL	SINGLE PHASE				"V" PHASE				THREE PHASE			
NOMINAL VOLTAGE	7.2 kV	7.62 kV	14.4 kV	19.9 kV	7.2 kV	7.62 kV	14.4 kV	19.9 kV	7.2 kV	7.62 kV	14.4 kV	19.9 kV
CONDUCTOR SIZE (ALUMINUM)					(OVERHEAD)							
336.6 kcmil									.321	.287	.0802	.0421
266.8 kcmil									.362	.323	.0907	.0473
4/0	2.01	1.80	.502	.263	1.01	.895	.251	.132	.423	.378	.106	.0553
3/0	2.22	1.99	.556	.291	1.11	.994	.278	.145	.483	.431	.121	.0633
2/0	2.57	2.30	.646	.337	1.29	1.15	.322	.168	.557	.497	.139	.0727
1/0	2.90	2.59	.727	.380	1.45	1.30	.363	.190	.646	.579	.162	.0851
2	3.67	3.27	.920	.480	1.83	1.64	.459	.240	.907	.808	.227	.119
4	4.85	4.33	1.21	.634	2.43	2.17	.607	.318	1.31	1.17	.328	.172
6	6.71	6.00	1.68	.882	3.36	3.00	.839	.440	1.94	1.73	.484	.254
					(UNDERGROUND)							
350 kcmil	1.05	.936	.267		.414	.370	.102		.265	.237	.0656	
250 kcmil	1.47	1.32	.373		.525	.469	.130		.336	.300	.0830	
4/0	1.74	1.55	.440		.593	.530	.147		.379	.339	.0939	
3/0	2.15	1.92	.542		.707	.632	.175		.451	.403	.112	
2/0	2.61	2.33	.656		.862	.769	.214		.548	.489	.136	
1/0	3.14	2.81	.789		1.03	.923	.257		.654	.584	.163	
1	3.74	3.34	.936		1.27	1.14	.318		.803	.717	.200	
2	4.40	3.93	1.10		1.56	1.39	.389		.978	.873	.244	

TABLE II
VOLTAGE DROP FACTORS
FOR
REA DISTRIBUTION LINES
FOR 90 PERCENT POWER FACTOR
VOLTAGE DROP FACTOR

	SINGLE PHASE				"V" PHASE				THREE PHASE			
LINE-TO-NEUTRAL NOMINAL VOLTAGE	7.2 kV	7.62 kV	14.4 kV	19.9 kV	7.2 kV	7.62 kV	14.4 kV	19.9 kV	7.2 kV	7.62 kV	14.4 kV	19.9 kV
CONDUCTOR SIZE (ALUMINUM)					(OVERHEAD)							
336.6 kcmil									.280	.250	.0702	.0367
266.8 kcmil									.319	.285	.0802	.0418
4/0	1.77	1.58	.442	.232	.882	.789	.221	.117	.377	.336	.0941	.0493
3/0	1.98	1.76	.495	.259	.988	.882	.247	.129	.436	.389	.109	.0570
2/0	2.31	2.06	.577	.302	1.16	1.03	.288	.151	.509	.454	.127	.0664
1/0	2.62	2.34	.652	.343	1.31	1.17	.327	.172	.600	.536	.150	.0782
2	3.38	3.02	.845	.443	1.69	1.51	.423	.221	.858	.765	.214	.112
4	4.57	4.08	1.14	.598	2.29	2.04	.571	.299	1.26	1.12	.315	.165
6	6.40	5.74	1.60	.839	3.21	2.86	.802	.421	1.88	1.68	.470	.246
					(UNDERGROUND)							
350 kcmil	1.02	.907	.258		.392	.350	.0965		.251	.224	.0618	
250 kcmil	1.42	1.27	.360		.499	.445	.123		.318	.284	.0786	
4/0	1.68	1.50	.424		.565	.505	.140		.361	.322	.0891	
3/0	2.07	1.85	.521		.677	.605	.168		.431	.385	.107	
2/0	2.51	2.24	.630		.830	.741	.206		.527	.470	.131	
1/0	3.01	2.69	.755		1.00	.892	.249		.631	.564	.157	
1	3.58	3.20	.896		1.24	1.11	.309		.780	.696	.194	
2	4.21	3.76	1.05		1.52	1.36	.379		.952	.851	.238	

TABLE III
VOLTAGE DROP FACTORS
FOR
REA DISTRIBUTION LINES
FOR 95 PERCENT POWER FACTOR
VOLTAGE DROP FACTOR

	SINGLE PHASE				"V" PHASE				THREE PHASE			
LINE-TO-NEUTRAL NOMINAL VOLTAGE	7.2 kV	7.62 kV	14.4 kV	19.9 kV	7.2 kV	7.62 kV	14.4 kV	19.9 kV	7.2 kV	7.62 kV	14.4 kV	19.9 kV
CONDUCTOR SIZE (ALUMINUM)					(OVERHEAD)							
336.6 kcmil									.233	.208	.0583	.0305
266.8 kcmil									.271	.242	.0677	.0354
4/0	1.50	1.34	.374	.196	.746	.671	.187	.0981	.324	.289	.0807	.0423
3/0	1.70	1.51	.423	.222	.845	.758	.212	.111	.382	.341	.0950	.0498
2/0	2.00	1.78	.500	.262	1.00	.895	.250	.131	.454	.405	.113	.0593
1/0	2.30	2.05	.574	.301	1.15	1.03	.287	.150	.544	.485	.136	.0708
2	3.05	2.73	.764	.400	1.53	1.36	.382	.200	.802	.715	.199	.104
4	4.24	3.79	1.06	.556	2.12	1.90	.531	.278	1.20	1.08	.300	.157
6	6.08	5.42	1.52	.795	3.04	2.72	.758	.398	1.81	1.62	.454	.238
					(UNDERGROUND)							
350 kcmil	.979	.874	.247		.366	.327	.0898		.234	.209	.0574	
250 kcmil	1.37	1.22	.345		.468	.418	.115		.299	.267	.0735	
4/0	1.61	1.44	.405		.533	.476	.131		.340	.303	.0837	
3/0	1.98	1.77	.497		.643	.574	.159		.408	.364	.101	
2/0	2.40	2.14	.600		.793	.708	.197		.502	.448	.125	
1/0	2.87	2.56	.716		.961	.858	.239		.606	.541	.150	
1	3.40	3.04	.849		1.20	1.07	.298		.753	.672	.187	
2	4.25	3.80	1.06		1.61	1.44	.403		1.01	.903	.252	

APPENDIX B

CALCULATING VOLTAGE DROPS BY COMPUTER

There are about as many ways to write a computer program as there are computer programmers. Also, a program written for one computer may not work on another. The computer input and output shown in this appendix is just an example of what can be done.

This particular program keeps a record of the number of users beyond each section, relieving the engineer of this duty. A numeric identifier for each point is used by the program rather than the alpha-numeric identifier, although the alpha-numeric identifier is used in the output.

When the program is run on a time sharing computer terminal, it will calculate the equivalent number of consumers (column 5 of the voltage drop sheet) and will request the peak kW (column 7 of the voltage drop sheet). This figure is obtained from Bulletin 45-2, Demand Factors. The program then calculates the sectional voltage drops and the total voltage drop at the end of each section.

The major portion of the program deals with sorting the data because the sectional voltage drops depend on the load after the section and the total voltage drops depend on the sectional voltage drops before the section in question. The equations below are used in calculating voltage drops:

$$\text{Equivalent consumers} = \frac{(\text{Consumers this section})}{2} + (\text{Consumers beyond this section})$$

$$\text{Equivalent concentrated load} = \frac{(\text{Concentrated load this section})}{2} + (\text{Concentrated load beyond this section})$$

$$\text{Total kW} = (\text{Peak kW}) + (\text{Equivalent concentrated load})$$

$$\text{Sectional voltage drop} = \frac{(\text{Total kW})\ (\text{Length of section})\ (\text{VDF})}{1000}$$

If a hard copy printout is not necessary, the above equations may be used with a programmable calculator. Such a calculator could be used to find the sectional voltage drops. A calculator may not have the memory or program storage available to find total voltage drops. The user would probably have to keep a record of the number of consumers and the amount of concentrated loads beyond each section.

A sample input and output from a computer terminal follows. Also included is description of the input data file.

SECTION			EQUIV CONSUMERS	ENTER PEAK kW
1A17	-	1A18	5	? 9
1A16	-	1A17	16	? 22
1AB15	-	1A16	26	? 33
1B20	-	1B21	5	? 9
1AB15	-	1B20	38	? 45
1ABC14	-	1AB15	92	? 101
1ABC13	-	1ABC14	100	? 107
1ABC13	-	1C24	20	? 27
1ABC1	-	1ABC13	202	? 203

VOLTAGE DROP BY SECTION — TOTAL VOLTAGE DROP

SECTION			VOLTAGE DROP	POINT	VOLTAGE DROP
1ABC1	-	1ABC13	4.35	1ABC13	4.35
1ABC13	-	1C24	1.43	1C24	5.78
1ABC13	-	1ABC14	.33	1ABC14	4.68
1ABC14	-	1AB15	1.27	1AB15	5.95
1AB15	-	1B20	1.42	1B20	7.37
1B20	-	1B21	.06	1B21	7.43
1AB15	-	1A16	.36	1A16	6.31
1A16	-	1A17	.26	1A17	6.57
1A17	-	1A18	.21	1A18	6.78

OUTPUT FROM COMPUTER TERMINAL

INPUT DATA FILE

Column	Description
1	Line numbers (ignored by program)
2 (First line only)	Number of sections
2 (All other lines)	Same as column 1 of Voltage Drop Sheet
3	Numeric identifier for point in Column 2
4	Same as columns 2 and 21 of Voltage Drop Sheet
5	Numeric identifier for point in Column 4
6	Same as column 3 of Voltage Drop Sheet
7	Number of consumers on taps (not other identified sections) connected to point identified in Column 4.
8	Same as column 8 of Voltage Drop Sheet
9	Concentrated loads on located on taps connected to point identified in column 4
10	Same as column 16 of Voltage Drop Sheet
11	Same as column 17 of Voltage Drop Sheet

00100	9									
00110	1A17	6	1A18	7	10	0	0	0	4.57	5.0
00120	1A16	5	1A17	6	6	3	0	0	4.57	2.6
00130	1AB15	4	1A16	5	4	5	0	0	4.57	2.4
00140	1B20	8	1B21	9	10	0	0	0	4.57	1.4
00150	1AB15	4	1B20	8	43	6	0	0	4.57	6.9
00160	1ABC14	3	1AB15	4	10	0	0	0	2.29	5.5
00170	1ABC13	2	1ABC14	3	5	0	12	25	1.26	1.9
00180	1ABC13	2	1C24	10	40	0	0	0	4.57	11.6
00190	1ABC1	1	1ABC13	2	120	0	209	0	1.26	10.0

INPUT DATA

APPENDIX C

METRIC CONVERSION FACTORS

It is recognized that some circuit diagrams may use dimensions in miles rather than kilometers. The following conversion factor is given for use in converting circuit diagrams to metric.

1 mile = 1.609 kilometers

APPENDIX D

Attached is a copy of a blank voltage drop sheet for local reproduction. REA will not stock this form.

*U.S. GOVERNMENT PRINTING OFFICE : 1978 0-261-520/REA-99

U. S. DEPARTMENT OF AGRICULTURE
RURAL ELECTRIFICATION ADMINISTRATION

VOLTAGE DROP SHEET

SYSTEM DESIGNATION	SUBSTATION	SYSTEM DESIGN
SYSTEM ENGINEER	CIRCUITS	DATE

SECTION		LOAD										LINE						VOLTAGE DROP		
		CONSUMERS					CONCENTRATED			TOTAL kW	POWER FACTOR	CONDUCTOR SIZE ALUMINUM	ϕ	kV	VOLTAGE DROP FACTOR	LENGTH OF SECTION IN km	kW·km			
SOURCE END	LOAD END	WITHIN THIS SECTION	BEYOND THIS SECTION	EQUIV. THIS SECTION	kWh PER MONTH	PEAK kW	WITHIN THIS SECTION	BEYOND THIS SECTION	EQUIV. THIS SECTION									THIS SECTION	TOTAL	AT POINT
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21